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Standard sigma-delta modulators use feedback around 1-bit quantizers to transform open loop integrator poles into closed loop transmission zeros of the noise transfer function. The DC transmission zeros permit high resolution quantization of data over a frequency band in their neighborhood. Closed loop zeros can be shifted to arbitrary spectral locations by doubling the number of integrators and then applying local feedback around integrator pairs thereby converting them to resonators. These spectrally shifted zeros support high resolution quantization at the selected (arbitrary) center frequency. In this paper we describe an alternate technique for shifting the open loop poles around the unit circle. In this method, rather than forming resonators, we use a spectral transformation on the baseband process performed by imbedded all-pass filters.

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USE OF ALLPASS NETWORKS
TO TUNE THE CENTER FREQUENCY OF SIGMA DELTA MODULATORS

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ABSTRACT:

Standard sigma–delta modulator use feedback around 1–bit quantizers to transform open loop integrator poles into closed loop transmission zeros of the noise transfer function. The DC transmission zeros permit high resolution quantization of data over a frequency band in their neighborhood. Closed loop zeros can be shifted to arbitrary spectral locations by doubling the number of integrators and then applying local feedback around integrator pairs thereby converting them to resonators. These spectrally shifted zeros support high resolution quantization at the selected (arbitrary) center frequency. In this paper we describe an alternate technique for shifting the open loop poles around the unit circle. In this method, rather than forming resonators, we use a spectral transformation on the baseband process performed by imbedded all–pass filters.

INTRODUCTION:

The sigma delta converter uses an over–sampling modulator with low resolution converters along with noise spectral shaping, via noise feedback, to realize high performance low cost analog–to–digital and digital–to–analog conversion at medium sample rates. The traditional modulator achieves a low noise power spectral density in a neighborhood of zero frequency by placing the zeros of the noise transfer function at zero frequency (ie. at $\omega = 0$). This relationship is shown in figure 1.

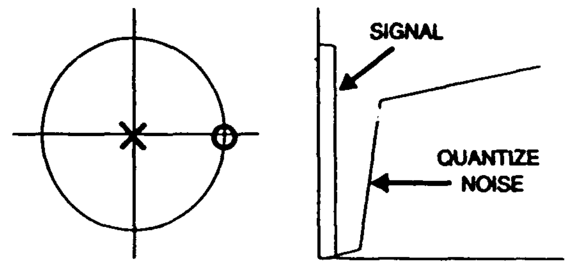

FIGURE 1. ZEROS OF BASEBAND NOISE TRANSFER FUNCTION

As suggested in figure 2. the filter function of the modulator loop resides in the feedback path of the quantizer hence the zeros of the noise transfer function are the poles of the open loop transfer function. This obvious relationship is shown in (1).

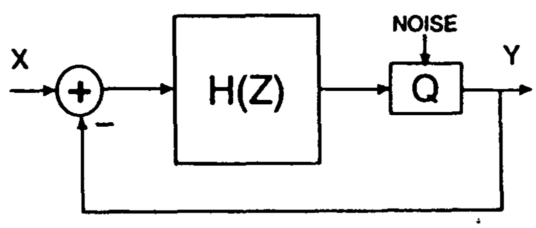

FIGURE 2. GENERIC SIGMA–DELTA MODULATOR

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$$Y(Z) = X(Z)\,\frac{H(Z)}{1+H(Z)} + Q(Z)\,\frac{1}{1+H(Z)} \tag{1}$$

$$H(Z) = \frac{N(Z)}{D(Z)}$$

$$Y(Z) = X(Z)\,\frac{N(Z)}{D(Z)+N(Z)} + Q(Z)\,\frac{D(Z)}{D(Z)+N(Z)}$$

The open loop poles are formed by the integrators of the modulator. The zeros of the noise transfer function suppress the noise spectral density in a processing bandwidth on the order of 1.0 to 2.0 percent of the sampling frequency. The particular location of the modulator's noise suppressed bandwidth happens to be at zero frequency because the loop intgerators are located at zero frequency. If the loop integrators are converted to resonators the location of the noise controlled suppressed bandwidth will coincide with the frequency location of the resonator. In this configuration, the sigma-delta modulator is a bandpass modulator. The bandpass location, of course, is confined to the first Nyquist interval of the sampling rate (ie. $\pm f_s/2$).

The advantages of using a bandpass converter to digitize a narrowband signal are many. These include elimination of the requirement for quadrature mixing to baseband, which requires quadrature carriers, matched balanced mixers, gain and phase matching of filters in the resulting I and Q channels, and two analog to digital converters. The very attractive attribute of the bandpass sigma-delta modulator is the ability to achieve the same wide dynamic range conversion (within its restricted bandwidth) for signals located anywhere in the oversampled frequency range. For instance, a converter with 50 KHz bandwidth operating with 64 times Nyquist samples at 3.2 MHz (probably by dividing a 6.4 MHz clock to assure pulse symmetry). A bandpass modulator can place the 50 KHz band anywhere in the 3.2 MHz frequency interval. The zero locations of a bandpass modulator are shown in figure 3.

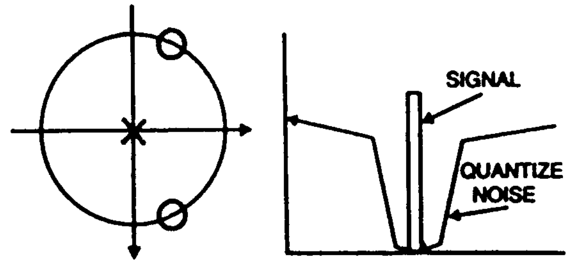

FIGURE 3. ZEROS OF BANDPASS NOISE TRANSFER FUNCTION

An important application of this capability is direct sampling of the commercial AM radio band which extends from 540 KHz to 1600 KHz. A receiver built in this manner would not require a tunable local oscillator, the first conversion to the IF frequency, or the IF amplifier chain. The RF amplifier would have to be capable of wide (linear) dynamic range. Once the signal is digitized, ordinary DSP techniques can be used to perform spectral shifts of the desired I and Q channels along with desired bandwidth and sample rate reductions. A receiver based on a bandpass sigma-delta is shown in figure 4.

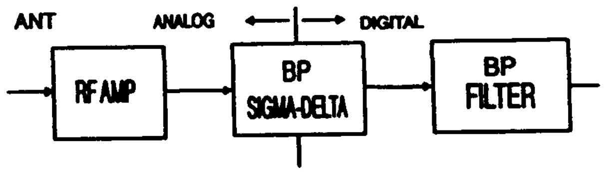

FIGURE 4. PASSBAND SIGMA-DELTA BASED AM RECEIVER

The traditional approach to transforming a

baseband sigma–delta to bandpass version is to apply local feedback around a pair of digital integrators to shift the pole pair to conjugate positions on the unit circle. This is shown in (2). Note if that the local feedback term α is set to 2.0, the resonator roots reside at the quarter sample rate, a very desirable location when forming a basebanding and filtering operation (an equivalent Hilbert Transform filter [1]). The approach we present here differs in that rather

$$H(Z) = \frac{\frac{Z}{(Z-1)(Z-1)}}{1+\frac{\alpha Z}{(Z-1)(Z-1)}} \tag{2}$$

$$= \frac{Z}{Z^2-(2-\alpha)Z+1}$$

than use local feedback, we perform a spectral transformation on a stable prototype system. We apply the standard lowpass to bandpass transformation shown in (3) and implemented as an allpass filter as shown in figure 5.

$$Z^{-1} \Rightarrow -Z^{-1}\frac{Z-\alpha}{1-\alpha Z} \tag{3}$$

$$WHERE\ \alpha = \cos\left(2\pi\frac{f_c}{f_s}\right)$$

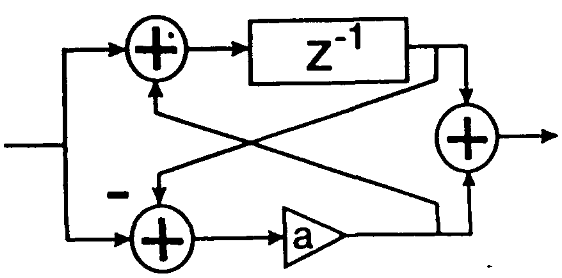

FIGURE 5. ALLPASS FILTER FOR SPECTRAL TRANSFORMATION

TRANSFER FUNCTION:

Figure 6 is a block diagram of a second order sigma–delta modulator which has used local feedback around a pair of integrators to separate the baseband zero in order to form a Tchebyshev stopband for the noise transfer function. When the spectral transformation identified in (3) is applied to this block diagram, we obtain the version shown in figure 7. The noise transfer function and the signal transfer function can be written but they offer little insight into the effect of the transformation. Rather, we demonstrate the effect in the following figures (8 through 10).

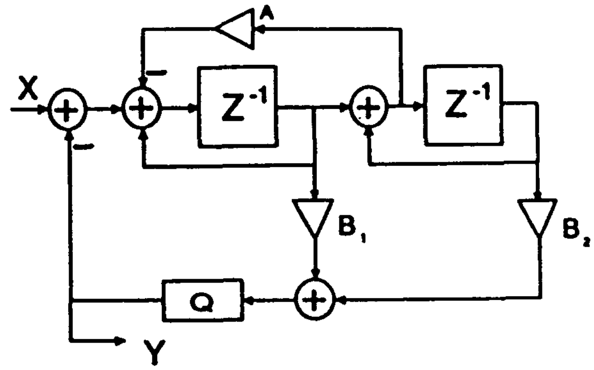

FIGURE 6. SECOND ORDER, SINGLE LOOP MODULATOR

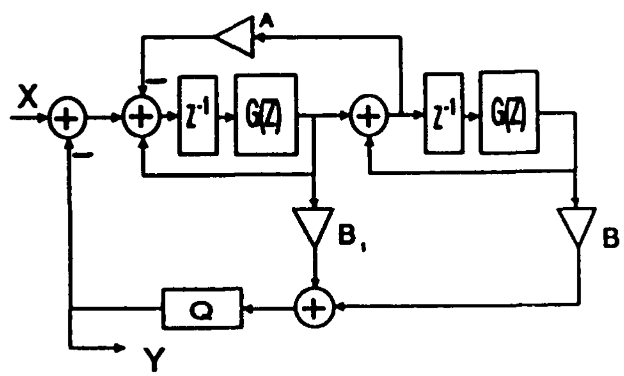

FIGURE 7. TRANSFORMED SECOND ORDER, SINGLE LOOP MODULATOR

Figure 8a presents the spectrum of the noise transfer function of the transformed loop corresponding to a spectral shift to the normalized frequency of 0.1. Note the preservation of the dual (separated) transmission zeros of the prototype second order modulator.

CONCLUSIONS:

We have presented a simple method of tuning the center frequency of a sigma–delta modulator. The technique works with any stable prototype. It entails the insertion of an tuneable allpass filter in cascade with each delay in the original prototype. We have demonstrated this method in modulators of up to fifth order. We have also incorporated this tuning method in cascade mash like structures which we have described in a companion paper at this conference ("New Architectures With Distributed Zeros For Improved Noise Shaping Of Delta–Sigma Analog To Digital Converters") We are extending this work to the digital filters following the modulator so that the resampl- ing filter tracks the tuning of the modulator. We have recently applied, on behalf of the Navy, for a patent on this process.

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1) Elliot, Doug. "Handbook of DSP", Chapter "Multirate Digital Filters". Academic Press, 1997.

2) Ribner, D.B. "A Comparison of Modulator Networks for High Order Oversampled Sigma–Delta Analog to Digital Converters:, IEEE Trans. on Circuits and Systems, pp 145–159, VOL.38, No.2, Feb. 1991.

3) Candy, J.C. and Temes, G.C. "Oversampl- ing Methods for A/D and D/A Conversion" in Oversampling Delta–Sigma Data Converters, IEEE Press, pp.1–25, (1992).